Visual Bio-composites - Establishing New Conditions for an Old Material

Hasling, Karen Marie

Publication date:
2011

Document Version:
Publisher's PDF, also known as Version of record

Document License:
Unspecified

Visual Bio-composites - Establishing New Conditions for an Old Material

Karen Marie Hasling
Designskolen Kolding
Ågade 10, 6000 Kolding; Denmark
+45 51211417
kmh@dskd.dk

ABSTRACT

The attention of most traditional fiber composites research goes to optimizing the mechanical properties as the typical applications for fiber composites are found in the transportation and wind turbine industries, where the necessity of light, strong and form-flexible materials helps to optimize the strength and shape in order to increase the efficiency of the systems.

It is believed that the market potential for fiber composites can increase by recognizing the existence and consequence of a visual value, regarded as just as important as traditional properties. This article includes two studies within the emerging field of visual and bio-composites and aims to establish a foundation for changing the perception of fiber composites and its applications.

Keywords

Fiber composites, sustainability, materials innovation, functional materials, aesthetics, building materials, textiles in architecture.

INTRODUCTION

A fiber composite is a material consisting of two separate components; a fiber (or textile) and a plastic. The fiber provides strength and the plastic encapsulates the fibers, holds them together and distributes load between them [4]. The material is technically attractive because of its combination of high tensile strength and low weight [3].

Within traditional fiber composites research most attention goes to optimizing the mechanical properties, determined by a number of parameters such as raw materials and manufacturing processes. The typical applications for fiber composites are found in the transportation and wind turbine industries, where the necessity of light, strong and form-flexible materials helps to optimize the strength and shape in order to increase the efficiency of the systems. For these applications the composite construction is usually hidden beneath layers of pigmented coatings that smoothen the surface in order increase the resistance to the environment and to reduce the air resistance. The pigmented coating, however, hides the textile structures, which are believed to possess a strong visual potential.

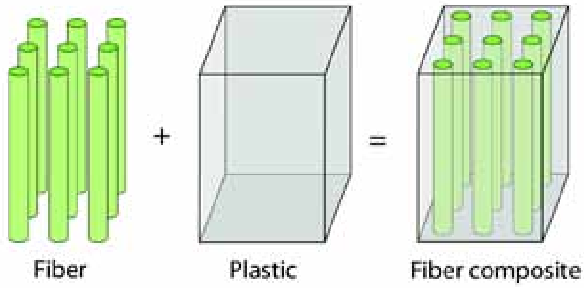

Figure 1: Schematic illustration of a fiber composite

Potentials in Architecture

In architecture there exist desire for building materials that enable organic and in general customized shapes with a unique expression. Façade modules in buildings, interior as well as exterior, are often attached to the building as an independent component, as shells, providing the wanted surface, and are thus subjected to no or limited bearing loads, which makes extraordinary mechanical properties unnecessary. Furthermore utilizing lighter building materials a lighter construction is necessary, which again saves materials and in the end money. With the concept of visual fiber composites the potential of adding an aesthetic value is emphasized.

Visual Fiber Composites

In a broad sense the vision of visual fiber composites is an attempt to create a mindset that recognizes the importance of the textile in fiber composites; making it the active component in the material while letting the plastic be a tool to encapsulate and protect the textiles from the surrounding environment. With this approach it should be possible to develop a multifaceted material that possesses strong textile associations such as comfort and coziness. It seeks to change the focus from wanting the strong material to wanting unique and attractive materials, with visual expressions and identities mainly defined by the textile contribution.

When demonstrating the mindset it has been further emphasized to challenge the common practice of industrial production of fiber composites by discussing how the introduction of new materials and alternative production processes can generate a visual attractive material with a strong environmental-friendly profile.

The studies

The studies included in the article seek to strengthen the concept of visual fiber composites. Hence one study has investigated the integration of functional elements in thermoplastic fiber composites to show how this could broaden the technical use of fiber composites and thereby make it attractive for new users, whereas another study demonstrated the concept of aesthetic fiber composites, obtaining their visual identity from textile structures and treatment techniques. The purpose of this was also to explore, which textile techniques that could be translated successfully into this new context.

The two studies were closely related and the discussions, results and conclusion will be treated as a whole and help to establish a holistic understanding of the concept.

DEVELOPMENT OF AN ENVIRONMENTAL-FRIENDLY MATERIAL ALTERNATIVE

These days environmental-friendly sustainability is on everybody's lips. Continuous climate changes, pollution, increasing population and overconsumption of global resources are clear indications that it is necessary to find alternative solutions, if we want to maintain our living standards in the Western World.

Material development is fast and continuing and new materials are invented, developed and optimized concurrently with increasing demands from industries, where the materials are used. This means that materials to a greater extent are developed for a specific purpose.

The Environmental Impact of Fiber Composites

It can be argued that fiber composites strengthen environmental-friendly architecture because of the ability to minimize the consumption of raw materials and constructing materials specifically developed for the purpose. In some aspects this is true, but most fiber composites today made from non-renewable raw materials that are difficult to recycle [17]. In the fiber composites industry thermosetting plastics are common as resins, partly because of a low viscosity making them easier to process. Because of their irreversible nature, thermosetting fiber composites are difficult to recycle and are usually re-used as e.g. landfill or burned. Furthermore it has, so far, not been possible to manufacture a thermosetting resin that does not release styrene when curing [16].

Using a thermoplastic resin the manufacturing conditions change because of the different plastic behaviors. Thermoplastics possess some properties that are regarded as beneficial in this context and with the thermoplastic bio-polymer PLA it is possible to manufacture a material from 100% renewable sources, that is recyclable and with an aesthetic strength that makes it an attractive alternative to existing building materials. A beneficial behavioral property is e.g. post-shapability due to a reversible solidification process.

Visual fiber composites – a good alternative to textiles

With the recognition of the importance of having a good indoor climate, the conditions for using textiles in the interior space are damaged. People use more than 90% of their lives indoor and the effect on substances found in buildings environments with a bad indoor climate has health implications [7]. Textiles can provide good acoustic environments, but is problematic due their porosity that generates high levels of loose fiber particle in the air. In public institutions such as hospitals and day cares the use of textiles are phased out as a result of aggravated requirement for hygiene and need of maintenance. Visual fiber composites keep the expressions known from textiles, but the materials are non-porous. Additionally using environmental-friendly materials no substances and diffuse to the air and by designing a proper surface, the material can reject dirt, dust and bacteria.

Choice of Materials

The used materials have been chosen from the vision of an environmental-friendly fiber composites with properties enabling the functional and visual elements in the studies.

Why natural fibers?

The common fibers used in fiber composites are glass, carbon or aramide fibers. These have good tensile properties, important in the applications fiber composites are used for today [2]. Research in natural fibers is driven by the wish to reduce the synthetic fibers' negative effect on the environment [1]. For fiber reinforcement mainly plant of vegetable fibers are used, which are characterized with a lower weight and lower manufacturing costs. Generally their mechanical properties are good and with a lower density, their specific tensile properties are better than their synthetic counterparts [2]. The quality of the fiber composites depends on the distribution of the resin around the fibers and prevention of air cavities. The cellulosic composition of the natural fibers facilitate the absorption of resin in the fiber, but cellulose molecules are hydrophilic and hygroscope, enabling them to absorb moisture, making them receptive to polluting substances [18].

In the studies mainly fabrics of cotton were examined. Even though cotton's tensile properties are less than e.g. ramie or flax, the fineness, uniformity can generate more delicate materials [8]. The studies focused on the fiber composites' visual expressions and the large selection of fabrics and available treatments for cotton made the natural fiber evident.

PLA – the plastic of the future?

Polylactid acid (PLA) is an aliphatic polyester made of renewable sources such as starch and sugar, which is fermented[1] by microorganisms in order to produce biologically degradable polymeric macromolecules. The polymer is based on lactid acid, which can occur in two different isomers, D(-)PLA, L(+)PLA. Polymerizing the monomer can create polymers with same physical properties, but with alternating mechanical properties as the isomers-distribution determine the polymers ability to crystallize. High content of L(+)-PLA produces crystalline PLA, while polymers with higher content than 15% D(-) PLA is amorphous [13].

As a sustainable material PLA is explicit, as good mechanical properties is combined with biocompatibility and biological degradation. It is possible to adjust properties by morphology, crystallinity and co-polymerization making both glass-like and rubber-like polymers occur [1]. In many aspects PLA has similar properties as other polyesters such as polyethylene terphtalate (PET), polypropylene (PP) and polyethylene (PE), but compared to the conventional plastics that have been commercially available since the 50s-60s, PLA still needs extensive further development. Nonetheless it is possible to translate some of the processes such as injection molding and extrusion as long as it is possible to prevent chemical, thermal and mechanical degradation during the processes [1].

EXPERIMENTS

The manufactured fiber composite laminate consisted of alternating layers of textiles and PLA-sheets. The function of the textiles was to contribute to the overall visual impact, to enable a function or to provide strength and stability. The visual textile laminas were made of woven, knitted and non-woven fabrics mainly from natural fibers being dyed, printed and else wise treated in different manners, whereas the stabilizing textile laminas were made of a plain cotton weave.

The laminates were manufactured in an industrialized thermo consolidation device at the Fiber Laboratory, Department for Materials Research, Risø DTU National Laboratory for Sustainable Energy. The process conditions were set to heating the lay-up to 190°C for 5 min in vacuum followed by consolidation for 1 min under pressure.

The manufacturing device enabled laminates with the dimensions 40x40cm; large enough to give an indication of the workability of the given material combination, but too small to fully understand its visual strength.

Part 1 – Functional Fiber Composites

The work with functional fiber composites aimed to illustrate the potential in integrating selected functional elements, which was emphasized to be beneficial for both the material's visual and functional value. The elements were chosen from a reckoned potential in an architectural-related context. After testing different elements, one was chosen for further development and put into a working concept.

Part 2 – Exploration of Textile Structures and Techniques

With the focus on using natural materials the textile design and technical inputs were also made with inspiration from nature. Based on the four elements *fire, air, earth and water* different textile designs were developed, combined and adapted to correspond with different textile structures and treatments in order to give a broad representation of materials.

Figure 2: Inspiration for the textile design with inputs from nature (photo: Louise Ravnløkke).

EXPERIMENTAL RESULTS

Part 1

Solar cells. Integrating solar cells would give a material able to generate energy from the sun. It would remind of the already-used glass/solar cell-material but be less sensitive than the fragile glass. The idea was good, but with the materials and processes used, the result was unsuccessful. The semi-crystalline solar cells used broke in the manufacturing process, possible due to the applied pressure and flow of the resin. Alternatives would be to use another solar cell such as amorphous solar cells, but their efficiency and service life are lower or manufacture the materials else wise.

Light-Emitting Diodes (LEDs). Integrating LEDs create a luminous material with appearance defined by the type, placement and control of the individual LED units. As for the solar cells the LEDs were also destroyed in the manufacturing caused by the combination of high temperature melting the diodes and the following pressure. The most apparent alternative would be to use a thermosetting resin and thereby also another process. Experiments carried out with this constellation were successful.

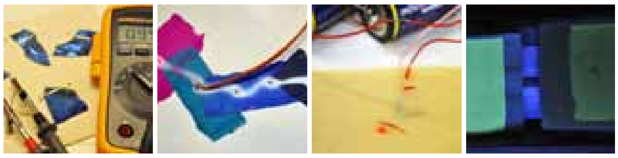

Figure 3: Representations of the preliminary experiments. From left: solar cells, thermochromic print, LEDs, phosphorescent print (photo: Karen Marie Hasling).

Phosphorescent print. Fiber composites with patterns in phosphorescent print give different visual appearance when it is dark. The intensity of light from the print was lower for

[1] Conversion of carbohydrates into alcohols or acids under anaerobic conditions.

textiles integrated in the fiber composite than for textiles themselves, but the function worked well.

Thermochromic print. Fiber composites with textile patterns in thermochromic print change when subjected to changing temperatures. In use the alternation could e.g. be caused by changing temperatures in the surrounding environment or by heating from an external or internal heating source. The integration proceeded without any problems.

In the continuous work thermochromic textile prints were combined with an internal heat source constructed of a conductive knit placed under the visual textile lamina in the fiber composite. This combination made the material fade in areas with the conductive knit, when an energy supply was put on. In the project hexagonal modules with different paths of conductive knit could be joined to create a large grid of slowly color-changing modules.

Figure 4: Representations of the final experiments with thermochromic print in a functional fiber composite. From left:The cross-section of the laminates, fastening the conductive knitted band to the textile, joint for connecting multiple modules, surface color change caused by internal heating (photo: Karen Marie Hasling).

Part 2

In general it was possible to manufacture fiber composite laminates with a strong visual appearance, where it was possible to maintain the visual textile contribution despite being integrated in a plastic matrix and being subjected to extensive heat and pressure during the manufacturing process. Furthermore it was shown that fine and delicate as well as coarse and irregular textile structures are suitable for this purpose and the spatial sense generated by the structure of the textiles and the composites lay-up is preserved.

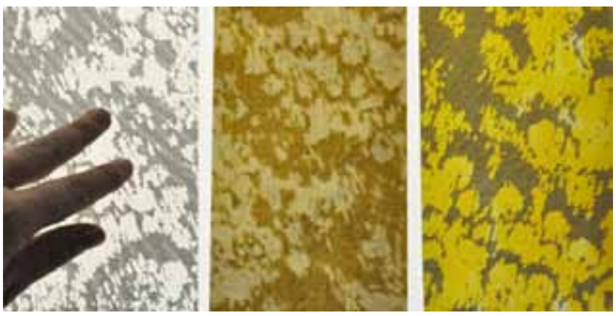

Figure 5: Representation of identical patterns of burn-out in different materials (photo: Karen Marie Hasling).

Many interesting effects were observed that have helped to understand how textiles can be represented as part of a fiber composite, making it easier in the future to choose and design materials and treatments and construct the right lay-up matching the desired outcome. Identical fabrics may appear differently with different background materials and different materials come out differently even with identical lay-up conditions; figure 6 shows good representations of this.

One of the main complexities was to predict the visual outcome of the lamination in advance, which appeared difficult as materials changed due to the temperature exposure, especially making the color of the textiles change. Furthermore some textiles were damaged by the heating due to thermal degradation of the materials, initiated by chemical degradations when treating the textiles. In figure 6 (left) a before and after picture of a laminate with a top layer of burn-out rayon is shown. The chemicals used in the burn-out treatment have damaged the fibers in the surrounding areas of the burn-out causing them to thermally degrade in the manufacturing process. In figure 6 (right) a before and after picture including a non-woven polyester layer is shown. Due to the lower melting temperature of the non-woven this has melted in the manufacturing causing the printed dye to flow out and mix into the PLA-matrix.

Figure 6: Adaption of expression from diffuse and flexible fabric (left) to integrated and rigid fabric appearance (right) (photo: Louise Ravnløkke).

MATERIAL PROPERTIES

Contributions of Fiber and Plastic

The fiber and the resin have different contributions to the overall material properties. Fibers are stronger than their plastic counterpart and will be determining the mechanical properties of the fiber composite. This even though the fiber volume fraction is usually lower than the matrix volume fraction. Unless post-treating the material only matrix will be present at the surface, making the material properties for the matrix responsible for environmental influences on the surface, such as chemical degradation, UV-degradation or bacterial degradation. Both the fiber and the plastic can influence the visual properties.

Mechanical properties	
Tensile strength	Fiber
Technical properties	
Chemical degradation	Plastic
UV-degradation*	Plastic
Bacterial degradation	Plastic
Burning properties	Plastic (& fiber)
Hygiene	Plastic

Visual properties	
Surface structure	Plastic
Integrated structure	Fiber
Colors and light diffusion	Fiber (& plastic)

Table 1: Overview of fiber and matrix contributions to the material properties (No literature on how fibers covered with plastic are influenced by UV has been found).*

In this study the mechanical properties have been neglected and it can be argued that the plastic is responsible for the technical properties whereas the main contribution of the fibers is to the visual outcome.

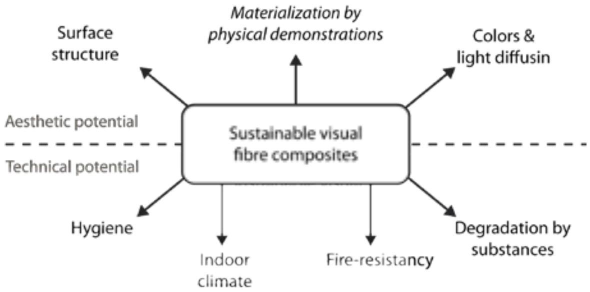

Figure 7: Dimensions of material properties.

Technical Properties

PLA is an emerging polymer and the behavior of fiber composites is non-linear. Therefore it can be difficult to translate results between different environments and situations.

Surface degradation

As PLA is composed of natural existing units it can be degraded by organisms, e.g. in the human body. It is a furthermore a polyester and will as other polyesters be degraded under certain conditions. Polyesters degraded in water, but the degradation rate is low and has limited practical importance. Under alkaline conditions (pH>7) the polymer degrade by hydrolysis, resulting in changing material surface character and corrosion [5, 9]. The visual appearance in will change, as this will cause color changes and surface textures.

Preventing thermal degradation

An untreated fiber composite consisting of a natural fiber and PLA would not pass a fire-test, which is necessary to make the material commercially accepted. Fiber composites can be fire-retarded by using a barrier, fire-retarding the fiber or fire-retarding the resin. In this case a barrier would impact the visual appearance of the material, which is undesired. Impregnating natural fibers with fire-retardant chemicals would influence the interfacial between the fiber and resin affecting both mechanical and visual properties. Moreover mainly the resin will be subjected to the fire source and the voluminous amount of fibers is lower than of resin.

By time it might be possible to co-polymerize fire-retarding molecules with PLA, as it is the case for the commercially available polyester Trevira CS [11]. This is advantageous because the fire-retardant is integrated in the polymer, which means that the effect will not decrease with use or cleaning [6]. Until then the fire-retardant chemicals have to be added to the polymer melt.

A considered part of the fire-retardants formerly used are strongly carcinogenic, but was convenient because they could be added directly to the melt [10, 12]. The availability of environmental-friendly fire-retardants is still limited. Apyrum from the company Deflamo AB consists of inorganic phosphorous salts. In aqueous solutions the chemical can impregnate e.g. textiles and paper, but in powder form the chemical could potentially be added to a melt [14]. Fire-retardants from organic compounds such as lignin and starch in an intumescent fire-retardant is studies by Reti et al. [15]. The results have been satisfying, but as lignin and starch are yellow-brown this will affect the appearance of the material.

COOPERATING ACROSS TRADITIONAL DISCIPLINES

An aspect of the studies has been to investigate how the different actors involved in the processes have worked together and realized the concept and its practice. The textile designs were made by two textile design students from Kolding School of Design without any previous experiences working with fiber composites. With their focus on the textile component only they designed designs and used technologies that challenged the further fiber composites manufacturing, especially by means of spatiality and temperature-caused material changes. In some cases this destroyed the expected visual expression but in other and often occurring cases, the materials got even more interesting and extraordinary.

Textile students are trained to understand and use textiles in contexts where textiles are commonly used. Being involved in the design process of the textiles and the fiber composites, the understanding on the technical properties of textiles improved and the importance of how the properties considered in the design process was emphasized. It can help the students to think out of the box and to explore other and untraditional uses of materials; textiles as well as any other material used in product development and architecture.

CONCLUSION

The studies have shown that it is possible to make aesthetically appealing bio-composites that add a visual or functional value to the material that makes it attractive for new markets such as architecture and the building industry. As it has shown possible to utilize well-known textile techniques to obtain this value addition, the question is how these techniques can be optimized in order to get the best results? It requires both knowledge and experience with textiles as well as fiber composites to fully understand and predict the future aspects of the material. The studies have successfully aimed to illustrate potentials of visual fiber composites, but the result only generates a fragment of the essential knowledge of the potentials of the physical material as well as for the market the material is believed to be perfect for.

ACKNOWLEDGMENTS

We thank the Danish Center for Design Research (DCDR) for financial support making it possible to execute the study on aesthetic fiber composites and the Fiber Laboratory, Department for Materials Research (AFM), Risø DTU National Laboratory for Sustainable Energy for making it possible to use their manufacturing facilities and materials for materializing both studies.

REFERENCES

1. Baillie, C. 2004. Green Composites – Polymer composites and the environment, Woodhead Publishing
2. Barbero, E.J., 1998. Introduction to Composite Materials Design, Taylor & Francis Inc.
3. Bunsell, A.R. & Renard, J. 2005. Fundamentals of Fiber Reinforced Composite Materials, IOP Publishing Ltd.
4. Callister Jr., and William D. 2007. Materials Science and Engineering: an Introduction, John Wiley & Sons, Inc.
5. Cam, D.; Hyon, S.-H. & Ikada, Y. 1995. Degradation of high molecular weight poly(L-lactide) in alkaline medium, Biomaterials 16: 833-843.
6. Deo, H.T., Patel, N.K. &Patel, B.K. 2008. Eco-friendly Flame Retardant (FR) Pet Fibers Through P – N Synergism. Journal of Engineered Fibers and Fabrics, Volume 3, Issue 4.
7. Fact Sheet: Toxic Chemicals in Building Materials - An Overview for Health Care Organizations, Global Health and Safety Initiative, May 2008
8. Hatch. K.L 1993. Textile Science. West Publishing Company.
9. Ho, K.-L. G. and Pometto, A.L. 1999. Effects of Electron-Beam Irradiation and Ultraviolet Light (365nm) on Polylactic Acid Plastic Films. Journal of Environmental Polymer Degradation, vol. 7, No. 2. 93-100.
10. Horrocks, A.R. and Price, D. 2001. Fire retardant materials, Woodhead Publishing.
11. How Trevira CS works, Trevira GmbH [online]. Available at: <http://www.trevira.com/en/textiles-made-from-trevira/home-textiles/flame-retardant-textiles-trevira-cs/how-trevira-cs-works.html?PHPSESSID=b4fff71dec8a486a1900eec3113b29ed> [Accessed 29 September 2011]
12. Kutz, Meyer 2005. Handbook of Environmental Degradation of Materials, William Andrew Publishing
13. Linneman, B.; Sri Harwoko, M. & Gries, T.H. 2003. Polylactide fibers (PLA), 426 Chemical Fibers International, Vol. 53, Dec. 2003.
14. Product Data Sheet – Apyrum Powder, Deflamo AB [online], Available at: <http://deflamo.se/mbo/index.php?option=com_docman&task=doc_download&gid=2&Itemid=191&lang=se> [Accessed 29 September 2011]
15. Réti, C.; Casetta, M.; Duquesne, S.; Bourbigot, S. & Delobel, R. (2008). Flammability properties of intumescent PLA including starch and lignin. Polymers for Advanced Technologies 19: 628– 635
16. Van De Velde, K. And Kiekens, P., 2001. Thermoplastic pultrusion of natural fibre reinforced composites. Composite Structures, 54(2-3), 355-360.
17. Van Rijswijk, K. And Bersee, H.E.N., 2007. Reactive processing of textile fiber-reinforced thermoplastic composites – An overview. Composites Part A: Applied Science and Manufacturing, 38(3), 666-681.
18. Wool, R.P and Sun, X.S. 2005. Bio-Based Polymers and Composites, Elsevier